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ARTICLE



Observed trends in diurnal temperature range over Nigeria

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ABSTRACT

The long-term trend of diurnal temperature range (DTR) over Nigeria was examined using daily station-based datasets for the period 1971–2013. The results show that the regionally averaged DTR has decreased significantly (-0.34°C per decade) over the Nigerian Sahel (north of 10°N), but there has been a slight increasing trend (0.01°C per decade) over the Nigerian Guinea Coast. The annual decreasing trend of DTR in the Nigerian Sahel is mainly attributable to the significant increasing trend in daily minimum temperature (T_{\min} , 0.51°C per decade), which far outstrips the rate of increase in the daily maximum (T_{\max} , 0.17°C per decade). In contrast, the comparable trends in T_{\min} (0.19°C per decade) and T_{\max} (0.20°C per decade) may explain the non-significant trend of the DTR averaged over the Guinea Coast region. It is observed that the DTR has decreased more in boreal summer (June–July–August) than in boreal winter (December–January–February) for the regions. Furthermore, it is found that the significant DTR declining trend over the Nigerian Sahel is closely associated with an increasing trend of annual and summer precipitation in the region, but the increasing DTR trend in the Nigerian Guinea Coast region can be attributed to the decreasing trend of cloud cover over the region.

摘要

本文基于站点观测及再分析资料，考察了1979–2013年期间尼日利亚不同地区温度日较差（DTR）的变化趋势及其可能原因。结果表明，尼日利亚北部萨赫勒地区（NSR）日最低温度的增温趋势显著大于日最高温度增加的趋势，导致该区域DTR呈显著下降趋势（ $-0.34^{\circ}\text{C}/10\text{年}$ ）；而在南部几内亚湾地区（NGC），区域平均日最高温度增加趋势略大于最低温度的增加趋势，导致该区域平均DTR呈微弱上升趋势（ $0.01^{\circ}\text{C}/10\text{年}$ ）。NSR区域显著的DTR下降趋势与该地区降水量呈长期增加趋势密切相关，而NGC区域DTR的增加趋势则可归因于该地区云量存在的长期减少趋势。

KEYWORDS

Diurnal temperature range; maximum/minimum temperature; trend; Nigeria

关键词

温度日较差; 日最高/最低温度; 趋势; 尼日利亚

1. Introduction

There are growing concerns on the decreasing trend of diurnal temperature range (DTR) over many land areas since 1950, which is mainly resulting from a larger increase in minimum air temperature (T_{\min}) relative to that of maximum air temperature (T_{\max}), especially in drier regions (IPCC 2007; Zhou et al. 2009). The DTR is defined as the difference between daily T_{\max} and T_{\min} , it embodies the asymmetric variation in the diurnal changes of these surface air temperatures, and it is considered as an indicator of climate changes because of its sensitivity to radiative energy balance (Karl, Karoly, and Arblaster 2004). Long-term trends in DTR have been investigated for different locations (Ding, Wang, and Lu 2018; Wang et al. 2014), and it is found that DTR has decreased over many land areas (Ding, Wang, and Lu 2018; You et al. 2016). Further results suggest that this decline may be attributable to the increasing effects of precipitation and cloud cover (Dai, Trenberth,

and Karl 1999), as precipitation can reduce the DTR by dampening T_{\max} through daytime evaporative cooling effects, and this effect could be larger in dry regions than in humid regions. On the other hand, clouds can also affect the DTR by reducing incident shortwave solar radiation to the Earth's surface during the day, which also dampens T_{\max} and increases T_{\min} through its ability to intercept outgoing longwave radiation (Dai, Trenberth, and Karl 1999; Zhou et al. 2009; Shen et al. 2014). However, the long-term trend of precipitation and cloud amount varies regionally, and this will lead to diverse DTR trends in different regions due to the combined impact of these factors (Zhou et al. 2009). For instance, Shen, Liu, and Lu (2017) observed a decrease in DTR in some climate regions but an increase in some others, and this underscores the need to evaluate DTR trends in different climatic regions, and further to investigate the associated influencing factors (Yang and Ren 2017).

As an important index of climate change, the DTR provides more information on climate change than the mean temperature (Karl, Karoly, and Arblaster 2004; Shen, Liu, and Lu 2017). Although the increasing trend of temperature extremes over Nigeria has been investigated by many previous studies (e.g. Abdulsalami 2015; Abatan et al. 2016), the DTR trend has not received considerable attention in Nigeria. As suggested in Dai, Trenberth, and Karl (1999), the precipitation effect on DTR could be larger in dry regions than in humid regions. Thus, it is interesting to examine the trends of DTR in the dry and humid zones of Nigeria, i.e. the Nigerian Sahel and Nigerian Guinea Coast, using station observations, and further to reveal the possible regional difference in DTR trends within the country, and the underlying factors that may be responsible for the regional differences.

In this paper, using a daily dataset from 16 meteorological stations for the period 1971–2013, we analyze the DTR trends in the aforementioned two climate regions of Nigeria. Furthermore, we make an attempt to investigate the possible factors responsible for the regional differences in DTR trends over Nigeria. The study area, data, and methods are described in section 2. The results, along with some discussion, comprise section 3, followed by concluding remarks in section 4.

2. Study area, data, and methods

2.1. Study area and data

Nigeria is located in the West African region between the latitudes of 4°N and 14°N and the longitudes of 2°E and 15°E and has a total area of approximately 925796 km² (Figure 1(a)). The climate is dominated by West African monsoon circulation; the prevailing winds transport moisture from the Gulf of Guinea in the low levels of the atmosphere. There are two major climatic regions in Nigeria: the Nigerian Sahel and Guinea Coast. These regions are characterized by variant climatic patterns (Nnamchi and Li 2011). In the Guinea Coast region, temperatures rarely exceed 32°C, but the humidity is very high and the nights are warm; whereas, in the Nigerian Sahel, midday temperatures rise above 36°C in summer, but with relatively cool nights, with the minimum temperature dropping as low as 19°C during the dry season. In this study, the DTR trend was investigated for the above-mentioned two regions of Nigeria. The Nigerian Sahel is delineated as (10°–15°N, 3.0°–15°W), while the Guinea Coast is delineated as (4°–10°N, 2.5°–15°W) (Figure 1(a)).

The data used in the analysis comprise daily rainfall, T_{\min} , and T_{\max} spanning 43 years (January 1971 to December 2013). These data were acquired from 16

synoptic weather stations of the Nigerian Meteorological Agency, and the datasets have been employed for many studies (e.g. Abatan et al. 2016). As shown in Figure 1(a), there are four stations (Gusau, Maiduguri, Bauchi, and Gombe) in the Nigerian Sahel region, and the other 12 stations are located in the Guinea Coast region. Monthly means of total cloud cover (TCC) from ERA-Interim are also used in the analysis. These data have a spatial resolution of 0.25° and cover the region (89.5°S–89.5°N, 0°–359.3°E) (Dee et al. 2011).

2.2. Methods

The temperature data were subjected to quality control and homogeneity assessment before being used in this study. DTR index was selected from the core indices recommended by CCI/CLIVAR/JCOMM ETCCDI (<http://etccdi.pacificclimate.org>) (Peterson 2005; Karl, Nicholls, and Ghazi 1999), which is defined as the difference between T_{\max} and T_{\min} (Peterson 2005). The inherent trends were computed using the Theil–Sen estimator (Theil 1950; Sen 1968) and tested for statistical significance based on the Mann–Kendall rank test (Mann 1945; Kendall 1975). A trend was considered to be statistically significant at $p < 0.05$ and $p < 0.1$. This method is widely accepted for its robustness in examining trends in climate data (e.g. Shen et al. 2014; Abatan et al. 2016). The correlation coefficients were tested for significance based on the Student's *t*-test.

3. Results and discussion

3.1. Spatial difference in DTR trends over Nigeria

In this section, we present the spatial difference in the DTR trends over different climate regions in Nigeria. Figure 1(b–f) show the annual and seasonal-averaged DTR trend at 16 meteorological stations over Nigeria during 1971–2013. It is found that the annual-averaged DTR has decreased significantly in the Nigerian Sahel and increased marginally over the Guinea Coast region. A closer look at the trends at the stations suggests that, in the Nigerian Sahel, the DTR has decreased significantly at three out of four stations over the region. Thus, the DTR has decreased significantly at a rate of -0.84°C , -0.32°C and -0.15°C per decade at Gombe, Bauchi and Maiduguri respectively, all of which are statistically significant at the 95% confidence level. Meanwhile, the decreasing trend at Gusau (-0.15°C) is not statistically significant. Relatively, in the Guinea Coast region, the DTR has decreased at six out of twelve stations. The declines at Ikeja (-0.19°C) and Lokoja (-0.17°C) are statistically significant at the 95% confidence level, while the declines at Ibadan (-0.03°C),

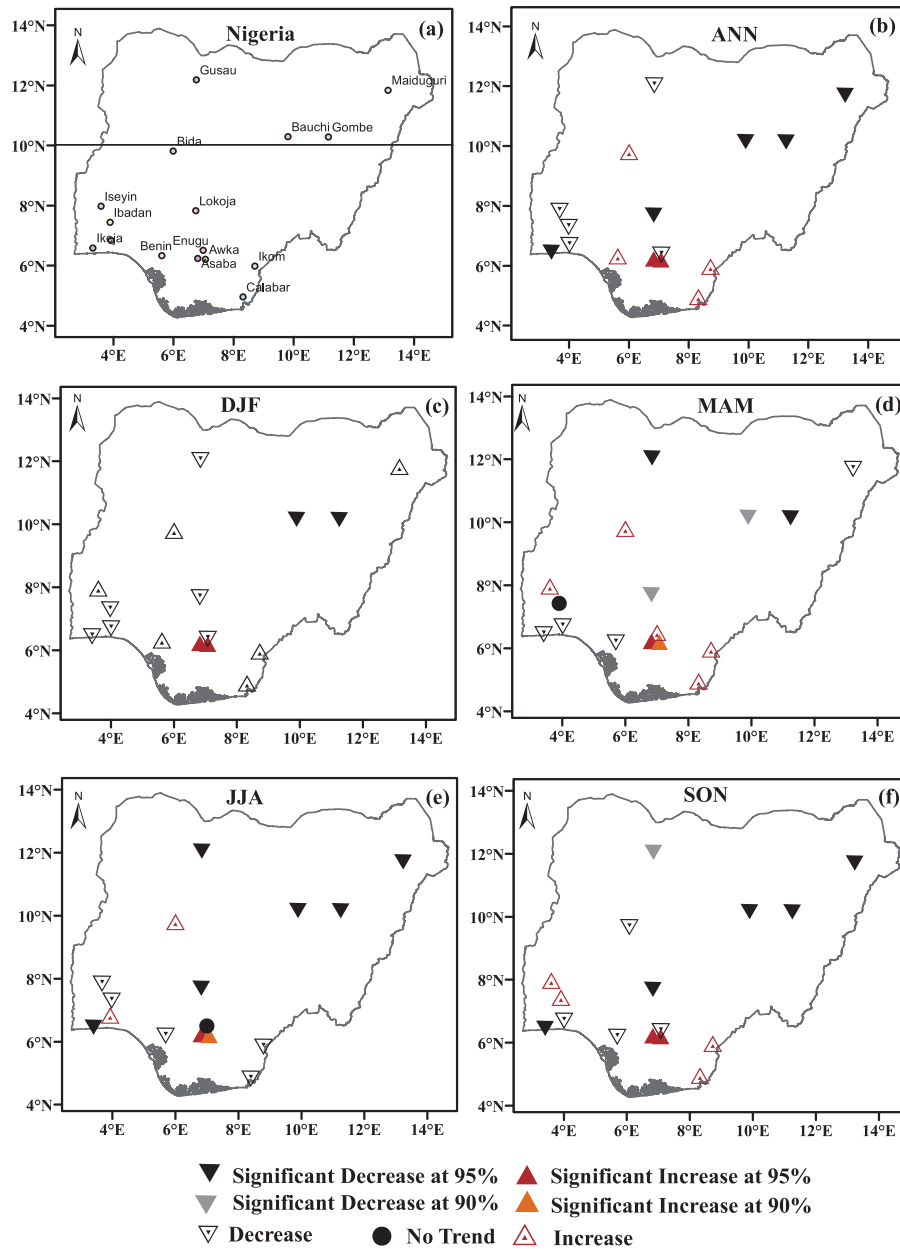


Figure 1. (a) Distribution of weather stations in Nigeria used in this study, with the horizontal black line demarcating the Nigerian Sahel (above) and the Guinea Coast (below). (b–f) Annual and seasonal trends of DTR across Nigeria. Upward-pointing triangles indicate positive Theil–Sen slopes, and downward-pointing triangles negative slopes. The back (gray) and red (brown) triangles are statistically significant at the 95% and 90% confidence levels respectively.

Ijebu (-0.06°C), Iseyin (-0.02°C) and Enugu (-0.02°C) are not. However, the DTR has increased at Awka and Asaba, at a rate of 0.26°C and 0.31°C per decade respectively.

However, the DTR trends vary seasonally. Figure 1(c–f) show the DTR trend in boreal winter (December–January–February, DJF), spring (March–April–May, MAM), summer (June–July–August, JJA), and autumn (September–October–November, SON) for each station (see Table 1 for the rates of change per decade). It is found that the magnitude of the DTR decline averaged over the Nigerian Sahel

region is larger during SON (-0.47°C) and JJA (-0.37°C) than in the DJF (-0.33°C) and MAM (-0.25°C) per decade, and this situation is relatively the same at nearly all stations over the region. At Maiduguri, the annual DTR has decreased significantly as a result of the large DTR decrease during JJA (-0.3°C) and SON (-0.15°C), which are statistically significant at the 95% confidence level. This is similar to the observed situation at Bauchi, where the significant annual downward trend of DTR is as a result of larger decreasing trends during SON (-0.05°C) and JJA (-0.34°C). At Gombe

Table 1. Seasonal and annual trends of DTR ($^{\circ}\text{C}$ per decade) over Nigeria. The superscripts 'a' and 'b' indicate trends that are statistically significant at the 95% and 90% confidence level respectively.

	Station	Location	DJF	MAM	JJA	SON	Annual
Sahel Nigeria	Gusau	12.17°N, 6.77°E	-0.1	-0.3 ^a	-0.17 ^a	-0.3 ^b	-0.15
	Maiduguri	11.83°N, 3.15°E	0.2	-0.1	-0.3 ^a	-0.2 ^a	-0.15 ^a
	Bauchi	10.28°N, 9.82°E	-0.28 ^a	-0.17 ^b	-0.34 ^a	-0.5 ^a	-0.32 ^a
	Gombe	10.27°N, 11.17°E	-0.13 ^a	-0.5 ^a	-0.06 ^a	-1.0 ^a	-0.84 ^a
	Nigerian Sahel	10°–15°N, 3–15°E	-0.33 ^a	-0.25 ^b	-0.37 ^a	-0.47 ^a	-0.34 ^a
Guinea Coast Nigeria	Bida	9.8°N, 6°E	0.06	0.06	0.03	-0.07	0.06
	Iseyin	7.97°N, 3.6°E	0.11	0.09	-0.05	0.07	-0.02
	Lokoja	7.82°N, 6.75°E	-0.02	-0.2 ^b	-0.2 ^a	-0.3 ^a	-0.17 ^a
	Ibadan	7.43°N, 3.9°E	-0.1	0	-0.004	0.01	-0.03
	Ijebu	6.83°N, 3.93°E	-0.12	-0.06	0.04	-0.05	-0.06
	Ikeja	6.58°N, 3.33°E	-0.15	-0.16 ^a	-0.2 ^a	-0.2 ^a	-0.19 ^a
	Enugu	6.5°N, 7.0°E	-0.07	0.01	0	-0.07	-0.02
	Benin	6.32°N, 5.6°E	0.13	-0.05	-0.02	-0.04	0.08
	Asaba	6.23°N, 6.82°E	0.5 ^b	0.4 ^a	0.3 ^a	0.5 ^a	0.31 ^a
	Awka	6.2°N, 7.07°E	0.47 ^c	0.16 ^d	0.1 ^d	0.25 ^b	0.26 ^b
	Ikom	5.97°N, 8.72°E	0.16	0.11	-0.003	0.07	0.06
	Calabar	4.95°N, 8.32°E	0.09	0.04	-0.03	0.07	0.06
	Nigerian Guinea Coast	4°–10°N, 2.5°–15°E	0.06	0.03	-0.005	0	0.01

(Gusau) the decline is also significant, at a rate of -0.6°C (-0.17°C) per decade in JJA, and -1°C (-0.3°C) per decade in SON. Although, there are indications of declines during DJF and MAM at the stations, the magnitude of the trends in SON and JJA is stronger. Indeed, the stations in the Nigerian Sahel have decreasing trends at annual and seasonal time scales.

In the Nigerian Guinea Coast, the regional-averaged DTR has decreased during summer (JJA) at about -0.005°C per decade, while there has been no noticeable change during SON. The region has also experienced increasing trends during DJF (0.06°C) and MAM (0.03°C) per decade. These differing seasonal trends explain the marginal increasing annual trend over the region. Moreover, the DTR has decreased at Benin at a rate of -0.02°C , at Calabar at a rate of -0.03°C , at Ibadan at a rate of -0.004°C , at Ikom at a rate of -0.003°C , and at Iseyin at a rate of -0.05°C per decade during JJA, but there is no noticeable change at Enugu. However, Bida and Ijebu have recorded a marginal increase at rates of 0.03°C and 0.04°C respectively per decade, while Asaba and Awka have recorded statistically significant increasing trends in all seasons, at 0.31°C and 0.26°C per decade respectively (Figure 1(b) and Table 1). During SON, the DTR has decreased at a rate of -0.04°C at Benin, while it has decreased at Bida, Enugu, Ijebu, Ikeja and Lokoja at rates of -0.07°C , -0.07°C , -0.05°C , -0.2°C and -0.3°C per decade respectively. In Figure 1(c), DJF is characterized by marginal decreasing trends at the stations; the trends are decreasing at rates of -0.07°C , -0.1°C , -0.12°C , -0.15°C and -0.02°C per decade at Enugu, Ibadan, Ijebu, Ikeja and Lokoja respectively, while the increasing trends seen at Benin, Bida, Calabar, Ikom and Iseyin are non-significant. The DTR has also decreased during MAM at some stations Lokoja (-0.2°C) and Ikeja (-0.16°C) recorded statistically

significant decreasing trends, while the decreasing trends at Benin (-0.05°C) and Ijebu (-0.06°C) are not statistically significant. The other stations show non-significant increasing trends, except Asaba and Awka with significant increasing trends, as illustrated in Figure 1(d). The above results indicate inhomogeneity in the seasonal DTR trends at the stations in the region, which characterizes the annual trend of DTR in the Nigerian Guinea Coast.

To investigate the relative effects of T_{\min} and T_{\max} on the variation in DTR in Nigeria, we present a comparison of their annual and seasonal time series. Standardized annual-averaged DTR anomalies during 1971–2013 over the Nigerian Sahel and Guinea Coast regions are shown in Figure 2, along with the time series of the annual mean T_{\max} and T_{\min} . The long-term linear trend of DTR is also shown in the figure. Figure 2(a) illustrates that, in the Nigerian Sahel, the annual DTR has decreased significantly. The rate of decline is -0.34°C per decade, and this decline is most obvious during 2000–2013. In this period, the DTR magnitude is smaller, the reason for which is that the magnitude of the increasing trend in T_{\min} is higher when compared with the increasing trend in T_{\max} ; specifically, T_{\min} increased at a rate of 0.51°C per decade during 1971–2013, which by far exceeds the 0.17°C per decade increase in T_{\max} in the Nigerian Sahel. The seasonal trends of DTR also suggest there has been a more significant decrease over the Nigerian Sahel. This decreasing trend is most notable in JJA -0.37°C and SON -0.47°C , as compared with DJF -0.33°C and MAM -0.25°C per decade (Table 2). During this period, T_{\min} increased rapidly compared with T_{\max} at the stations. For instance, at Bauchi, T_{\min} increased significantly in all seasons, while the T_{\max} increase was less significant. More specifically, T_{\min} increased during DJF, MAM, JJA and SON with magnitudes of 0.5°C , 0.4°C , 0.5°C and 0.6°C per decade

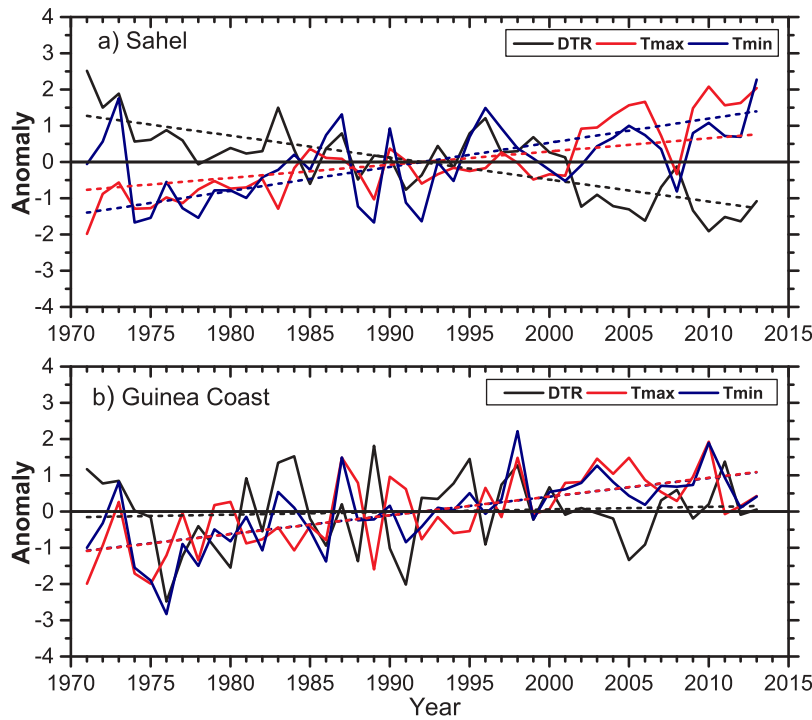


Figure 2. Normalized time series of annual-averaged DTR, T_{\max} and T_{\min} over (a) the Nigerian Sahel and (b) Guinea Coast. The dotted lines are trend lines.

Table 2. Seasonal trends of DTR, T_{\max} , T_{\min} ($^{\circ}\text{C}$ per decade), precipitation (PRE) (mm per decade) and TCC (0–1) averaged over two regions in Nigeria. The superscripts 'a' and 'b' indicate trends that are statistically significant at the 95% and 90% confidence level respectively.

	Sahel					Guinea Coast				
	DTR	T_{\max}	T_{\min}	PRE	TCC	DTR	T_{\max}	T_{\min}	PRE	TCC
DJF	-0.33^a	-0.03^a	0.57^a	0	0.03^a	0.06	0.29^a	0.22^a	0.10	0.01
MAM	-0.25^b	0.19^a	0.46^a	-1.00	0.001	0.03	0.21^a	0.17^a	4.80	-0.01
JJA	-0.37^a	-0.01	0.36^a	10.0^b	-0.03^b	-0.005	0.15^a	0.17^a	7.00	-0.01^a
SON	-0.47^a	0.09	0.58^a	5.40^b	-0.01	0	0.17^a	0.21^a	5.80^b	-0.002
ANN	-0.34^a	0.17^a	0.51^a	4.20^a	-0.01	0.01	0.20^a	0.19^a	4.00^b	-0.07

respectively, while T_{\max} increased at 0.2°C , 0.2°C , 0.15°C and 0.14°C per decade during DJF, MAM, JJA and SON respectively. This is practically the same situation as at the stations where the DTR has decreased significantly. Nonetheless, this analysis shows that the significant decreasing DTR in the Nigerian Sahel is demonstrative of the fact that the rate of increase in T_{\min} has exceeded the rate of increase in T_{\max} (Figure 2(b)).

Figure 2(b) shows the interannual variation and trends of the DTR averaged over the Guinea Coast. It is evident that the DTR has increased marginally, at a rate of 0.01°C per decade in the region. This is connected to the significantly increasing T_{\min} (0.19°C) and T_{\max} (0.20°C) per decade. Obviously, the T_{\max} narrowly increased by as much as the T_{\min} , and this perhaps explains the marginal increase in DTR in the region. However, there are some differences among stations (Table 1). For instance, the DTR has decreased significantly at Ikeja. On closer inspection, at

this station, the variation of seasonal trends in T_{\min} and T_{\max} suggests that T_{\min} has increased at rates of 0.43°C , 0.38°C , 0.33°C and 0.36°C per decade in DJF, MAM, JJA and SON respectively, while T_{\max} has increased at rates of 0.3°C , 0.20°C , 0.14°C and 0.20°C per decade. Meanwhile, at Awka, where the DTR has increased, the rate of increase in T_{\max} has outstripped the rate of increase in T_{\min} in all seasons. The disparity in the increase in T_{\min} and T_{\max} at the stations in the Nigerian Guinea Coast region may have contributed to the non-significant increasing annual DTR trend for the region.

3.2. Possible reason for the regional difference in the DTR trend over Nigeria

It has been found that the DTR shows a strong inverse correlation with rainfall amount and cloud cover (Zhou et al. 2009; Wang et al. 2014; You et al. 2016). To investigate

the possible reason for the regional difference in the DTR trend over the Nigerian Sahel and Guinea Coast regions, we examine the effects of precipitation and cloud cover on the DTR trends in these two climatic regions of Nigeria.

Figures 3(a,b) show the normalized time series of the regional-averaged DTR and precipitation for SON and JJA over the Nigerian Sahel and Guinea Coast regions, wherein the straight lines indicate the long-term linear trend. There is an indication that, when the DTR is low, precipitation is relatively high and, conversely, when precipitation is low, the DTR is high. To further strengthen this point, we also examine the correlation between the interannual variation of DTR and rainfall, the results of which suggest the annual-averaged rainfall is negatively correlated with the annual-averaged DTR in the Nigerian Sahel, with a correlation coefficient of $r = -0.37$, and in the Nigerian Guinea Coast region with $r = -0.25$. This indicates that the correlation between DTR and rainfall over the Nigerian Guinea Coast is relatively weak, while the correlation over the Nigerian Sahel is significant at the 95% confidence level.

Furthermore, in the Nigerian Sahel, the time series of the seasonal-averaged DTR and precipitation are well related, with correlation coefficients of -0.53 , -0.49 and -0.36 during JJA, SON and MAM respectively; although, a non-significant positive correlation ($r = 0.18$) can be

found during DJF. Meanwhile, in the Nigerian Guinea Coast region, the correlation coefficient is 0.002 for JJA and -0.07 for SON, inferring a weak relationship between DTR and precipitation during boreal summer in the region. Conversely, there are significant negative correlations of $r = -0.54$ and $r = -0.42$ for DJF and MAM respectively. The large difference in the correlation coefficient during boreal summer and winter perhaps explains the non-significant negative correlation found between the annual-averaged DTR and precipitation in the region. This is consistent with the findings of Dai, Trenberth, and Karl (1999), who suggested the effect of precipitation on DTR could be larger in dry regions than in humid regions.

The trends of seasonal and annual mean rainfall averaged over the Nigerian Sahel suggest that rainfall has increased significantly in JJA, at a rate of 10 mm per decade during 1971–2013, and 5.4 mm per decade in SON (Figure 3(a) and Table 2). Similarly, the trend implies that it has increased at a rate of 4.2 mm per decade annually over the region. Furthermore, Lin and Dike (2018) suggested that there are more incidence of heavy rainfall in the region. This shows that a significant decline in DTR over the Nigerian Sahel is well connected with the significant increasing rainfall over the region, and this can be explained by the damping effect of precipitation on T_{\max} through evaporative cooling

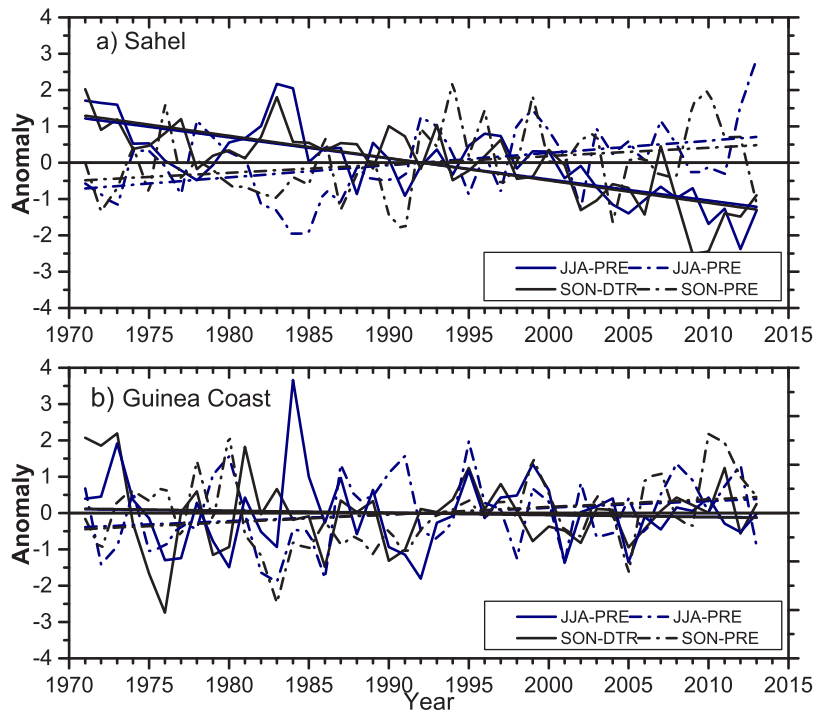


Figure 3. Normalized time series of seasonal (JJA and SON) DTR and precipitation anomalies during 1971–2013 (thick and dotted lines show the DTR and precipitation anomalies respectively, while the straight lines are trend lines) over (a) the Nigerian Sahel and (b) the Guinea Coast.

(Zhou et al. 2009; Shen et al. 2014). Relatively, the rate of rainfall has also increased over the Nigerian Guinea Coast, at a rate of 7 mm per decade during JJA and 5.8 mm per decade during SON (Figure 3(b)), while it has increased annually at a rate of 4 mm per decade in the region. Meanwhile, the annual-averaged DTR trend is found to be increasing marginally, at 0.01°C per decade, with a maximum increasing trend of DTR found in DJF. This suggests that the increasing DTR trend found in the Nigerian Guinea Coast region cannot on the whole be explained by the increasing trend of rainfall in the region.

In order to investigate the possible reason for the increasing DTR trend in the Nigerian Guinea Coast region, we further analyze the annual time series of

averaged TCC and DTR over the two climatic regions in Nigeria, as shown in Figure 4. It can be seen from Figures 4(a,b) that TCC has decreased in the two regions. Given that cloud is inversely correlated with DTR, as more cloud can dampen the T_{\max} and increase the T_{\min} (Dai, Del-Genio, and Fung 1997; Dai, Trenberth, and Karl 1999; Zhou et al. 2009), the decreasing trend of cloud cover in the Nigerian Guinea Coast region might be responsible for the increasing DTR trend (Table 2). To strengthen this point that DTR and TCC are connected in the region, we also calculate the correlation coefficient between annual DTR and TCC in these two regions. It is found that annual DTR and TCC are negatively correlated with correlation coefficient $r = -0.45$ in the Nigerian Guinea Coast and $r = -0.15$ in the Nigerian

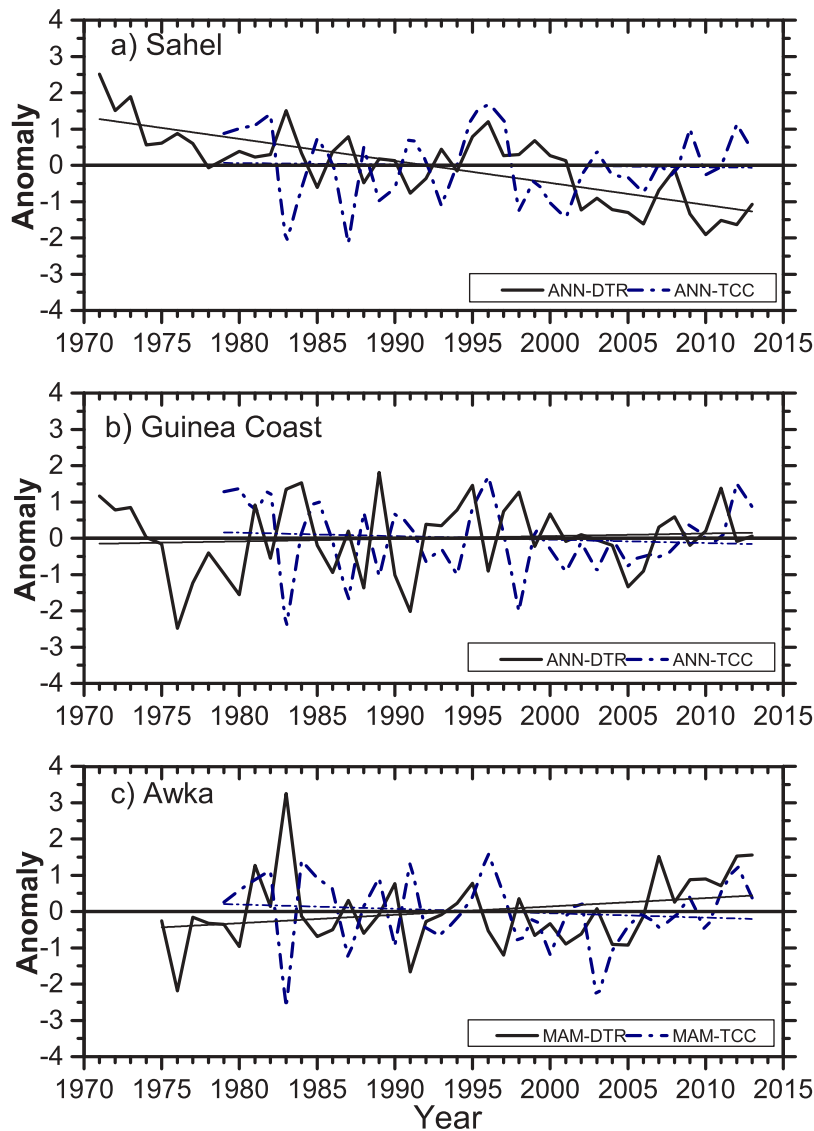


Figure 4. Normalized time series of annual DTR anomalies during 1971–2013 and ERA-Interim TCC anomalies during 1979–2013 (thick and dotted lines show the DTR and TCC anomalies respectively, while the straight lines are trend lines) over (a) the Nigerian Sahel, (b) the Guinea Coast, and (c) for Awka (MAM).

Sahel as shown in Figure 4(a–b). This indicates that the correlation between DTR and TCC over the Nigerian Guinea Coast is statistically significant, while that over the Nigerian Sahel is relatively weak. This suggests that the effect of TCC on DTR is more pronounced in the Guinea Coast than in the Nigerian Sahel, which is an indication that the decreasing cloud cover in the Nigerian Guinea Coast region has an important effect on the increase in T_{\max} . To show that the effect of TCC is significant in the Nigerian Guinea Coast region, we present in Figure 4(c) the connection between the DTR and TCC in Awka, where the DTR increasing trend is relatively larger during the MAM season. With correlation coefficient of $r = -0.29$ when the time series are detrended, it indicates that DTR and TCC are inversely correlated during the MAM season. This suggests that increasing DTR is associated with decreasing cloud cover at the station as shown in Figure 4(c).

The above results further explain the regional difference in DTR in these two regions of Nigeria, which indicates that increasing precipitation in the Nigerian Sahel is well connected to decreasing DTR in the region while decreasing cloud cover is related with the marginal increase in DTR over the Nigerian Guinea Coast region.

4. Conclusions

In this study, the trends of DTR in Nigeria during 1971–2013 are examined based on observed station data. The inherent trends of DTR, T_{\min} , and T_{\max} , as well as the possible influence of precipitation and cloud cover, are also investigated. In the Nigerian Sahel, the annual DTR trend shows a significant decline over the region at the 95% confidence level. Furthermore, the seasonal trends show that the DTR has decreased significantly during JJA and SON, more so than during DJF and MAM. The decreasing trends are associated with a faster warming of T_{\min} , which outstrips that of T_{\max} , during 1971–2013 in the Nigerian Sahel. Relatively, the annual trends in DTR have increased marginally in the Nigerian Guinea Coast region, and the seasonal trends over the region suggest a marginal increase, especially during DJF and MAM. The slight increasing annual DTR trend is an indication that T_{\min} and T_{\max} have increased symmetrically over the region.

Meanwhile, there is an inverse relationship between precipitation and DTR over Nigeria; the significant decreasing DTR trend is well associated with a significant increasing rainfall trend, and this is evident in the Nigerian Sahel. The increase in precipitation over the region has tended to dampen the increase in T_{\max} , while T_{\min} has increased

rapidly. However, the impact of the precipitation trend on the DTR trend is not explicit in the Nigerian Guinea coast region, where a slight increase in the annual DTR is found with the increasing rainfall trend. Further analysis reveals that a decreasing trend of TCC exists in both the Nigerian Sahel and Guinea Coast region, and there also exists an inverse relationship between DTR and cloud cover over Nigeria, especially in the Nigerian Guinea Coast region. The decreasing trend of TCC is associated with the marginally increasing trend of DTR in the Nigerian Guinea coast region, while the effect of cloud cover on DTR over the Nigerian Sahel is relatively weak. This demonstrates that precipitation and cloud cover largely determine the patterns of DTR variability in Nigeria.

Disclosure statement

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